Abstract: We installed a very sensitive solar neutron telescope at Mt. Sierra Negra (4,600 m above sea level) in Mexico in April, 2013. This new solar neutron telescope is four times more sensitive than the current solar neutron telescope at Mt. Sierra Negra, due to its high detection efficiency of neutrons. This project is called SciCRT (SciBar for the Cosmic Ray Telescope). The data taking speed of the current system is limited to 1 kHz, although the expected count rate of background neutrons is 20 kHz. To reduce the data taking dead time, we started to develop a new system using SiTCP to replace the current system which uses traditional VME. SiTCP enables us to transfer high speed data from Field Programmable Gate Array to DAQ PC with Transmission Control Protocol. We could achieve the readout speed of 48 kHz in some specific condition, and we are continuing several tests to apply this new system to a more realistic experimental situation. In this paper, we will present details of the design of the new data taking system and several tests performed to achieve a fast readout.

Keywords: solar neutron, SciCRT, SiTCP

1 Introduction

Solar flares are studied using electromagnetic radiation and particles by various instruments. We particularly focus on particle detection. Our purpose is to understand the acceleration mechanism of ions. The accelerated ions generate $\gamma$ rays, pions and neutrons by interaction with the solar atmosphere. Line $\gamma$ rays and $\gamma$ rays from neutral pions have been observed by many instruments such as RHESSI and Fermi-LAT. FIB detector onboard the Space Environment Data Acquisition equipment-Attached Payload (SEDA-P) in the International Space Station (ISS) can observe low energy neutrons (lower than 100 MeV). On the other hand, we have observed neutrons using ground level detectors. As neutrons are attenuated by the atmosphere, we can observe high energy neutrons (higher than 100 MeV).

For the solar neutron detection at the ground level, we installed seven solar neutron telescopes at high mountain s of different longitudes in the world near the equator. By using the solar neutron telescopes, we succeeded in detecting about ten solar neutron events [1, 2]. The number of solar neutron events is not statistically enough, and it is desirable to install a new detector which is more sensitive to neutrons and has a better energy resolution than the current ones.

We installed the SciBar [3] on Mt. Sierra Negra in Mexico, which is 4,600 m above sea level. This project is called as SciCRT, which stands for SciBar for the Cosmic Ray telescope.

2 Detector

A schematic view of the SciBar detector is shown in Fig. 1. The SciBar detector consists of 14,848 scintillator bars, whose dimension is 300 cm $\times$ 2.5 cm $\times$ 1.3 cm. There are 64 layers. Each layer is made of two planes with 116 scintillator bars orthogonally attached. The total volume of the SciBar detector is 3.0 m $\times$ 3.0 m $\times$ 1.7 m. A charged particle penetrating inside the scintillator bar emits scintillation photons. The scintillation photons go through a wave length shifting (WLS) fiber, and are read out by 64-channel multi anode photomultiplier tube (MAPMT).

The SciBar detector was used for a neutrino experiment at Fermilab in USA after the K2K neutrino oscillation experiment. In 2011, the detector was transferred from Fermilab to the Instituto Nacional de Astrofisica, Optica y Electronica (INAOE) in Mexico. In April 2013, the detector was transferred to Mt. Sierra Negra (4,600 m); the calibration experiment was performed in May. The study on this calibration experiment is presented on a separate paper [4].
3 Electronics

3.1 Data taking system

We are currently using the electronics of the SciBar detector, which was developed at Kyoto University in Japan [6]. The basic configuration of the electronics consists of the MAPMT, the front-end electronics and the back-end electronics. A block diagram of the circuits is shown in Fig. 2. One back-end board corresponds to eight MAPMTs. We adopted 100 Mbps SiTCP instead of VME bus. This means that we can not detect solar neutron signals efficiently even if the efficiency of the detector is good. Therefore we need to improve a new back-end boards so that we can do a fast readout.

signals from two MAPMTs. We adopted 100 Mbps SiTCP for this prototype.

Fig. 3: A block diagram of the new electronics, including a prototype of the back-end board

3.2 Front-end electronics

We are using the front-end board (FEB) that were developed at Kyoto University in Japan. A combination of ASICs (VA32_HDR11 and TA32CG) is employed in the FEB. The signal from MAPMT is sent to a fast shaper in the TA32CG (TA). It makes a fast shaping signal, whose peak can be adjusted from 0.8 to 1.2 μs. This fast shaping signal goes through a discriminator, which generates a hit signal (Ta) such as in Fig. 4. A slow shaper forms a slow shaping signal keeping a voltage value in VA32_HDR11 (VA). When the VA receives a hold signal (Hold_b) from an external circuit, the voltage values of 64-channel are held at that moment. These voltage signals are serialized by an analog multiplexer and sampled (Outm) synchronized with an external clock (Clock_b). The VA/TA readout system is controlled sequentially by the digital circuit (FPGA) on the BEB in Fig. 4. Details of this readout system are explained in [6].

Fig. 4: The basic behavior of 32-channel VA and TA [6]. The red lines and the signal names with subscript express the analog signals. The blue lines express the digital signals. TA has lower two signals (Fast-shaper and Ta). On the other hand, the Others (Slow-shaper, Hold_b, Shiftin_b, Clock_b, Shiftout_b, Outm) are included in VA. The signal of Shiftin_b shows the start of VA readout. The signal of Shiftout_b also shows the finish of VA readout.
3.3 Back-end electronics

A prototype of the back-end board (BEB) is composed of the VA/TA interface board, the isolation board, the FPGA board and the SiTCP board. The VA/TA interface board is a VA/TA interface circuit which can give and receive the sequential control signals between the FEB and the FPGA board. As a result of the sequential control, the voltage signal of each channel is digitized by the flash-ADC in turn. The isolation board can isolate the grounds between the analog and digital circuits as an antinoise measures. The FPGA board behaves as a digital circuit for the VA/TA sequential control and transfer the ADC values to the SiTCP board. The XC3S700AN-4FGG84 FPGA made by Xilinx Inc. is employed on this FPGA board. We used the Spartan-3AN Starter Kit made by Xilinx Inc. as the SiTCP board. There are Ethernet 10/100 PHY, EEPROM and XC3S700AN-FG484 FPGA on this board, which are needed to actuate SiTCP. We implemented the SiTCP circuit on the FPGA of this Starter Kit. By using SiTCP, we can transfer the ADC values using TCP/IP protocol.

Fig. 5: A Photograph of the BEB prototype

4 Performance

We estimated the transfer time from the FPGA board to a DAQ PC using dummy ADC values. We controlled the generated rate of these dummy ADC values using a clock. We estimated the transfer rate from the data volume per a constant time on a DAQ PC. The received rate increased linearly when we increased the generated rate up to 95 Mbps as shown in Fig. 6. This speed of 95 Mbps is equal to the trigger rate of about 92 kHz for neutrons. Because the neutron trigger rate is about 20 kHz at Mt. Sierra Negra, the result in Fig. 6 shows one BEB that handle the signals from four MAPMTs at the observation.

Fig. 6: Evaluation of the transfer rate using dummy AD-C signals. The yellow line shows the trigger rate of background neutrons at Mt. Sierra Negra. The red line is an ideal line.

Next, we confirmed the linearity of ADC on the VA/TA interface board of the BEB prototype. We measured the output values of ADC while changing the input voltage. This result is plotted in Fig. 7. For our observation, the pedestal signals are equal to a value of around 2,000 ADC and the real cosmic ray signals occupy from 2,000 to 4,000 ADC values. Therefore we achieved the linearity of ADC within 5% for observing neutrons.

Fig. 7: Linearity of the ADC. The abscissa is the input voltage and the ordinate is corresponding ADC. The red line express a fitting line for the data plots. The purple dots show gaps from the fitting line.

Moreover, we obtained cosmic ray muon signals using a combination of one MAPMT and scintillator bar, on the SciBar detector. A map of photon intensity at the 64-channel MAPMT anode is shown in Fig. 8. We can also see the cross talk around the channel where the fiber is attached. The ADC histogram of cosmic ray muons using electronics including the fast readout BEB prototype is shown in Fig. 9.
5 Conclusion

We installed the SciBar detector on Mt. Sierra Negra in Mexico, at 4,600 m above sea level. This project is called SciCRT. We performed the calibration experiment on May in 2013. We will soon start the continuous observation for the galactic cosmic ray and the solar neutron detection. To further improve the performance of SciCRT, we started to develop a prototype of a new BEB and adopted the Ethernet transfer using SiTCP instead of VME bus to achieve the fast readout of neutrons. We tested the event rate and the linearity of this readout system, and could obtain that we can record neutrons with the rate of 20 kHz by four 64-channel MAPMTs, with a linear response of the ADC within 5%. We have planned further developments that will be able to replace the whole system by this new system.

6 Acknowledgement

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References